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Performance based Comparison of Wind and Solar Distributed Generators using ENVVI and NSGA II

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ABSTRACT

Distributed Generation (DG) technologies have become more and more important in power systems. The objective of the paper is to optimize the distributed energy resource type and size based on uncertainties in the distribution network. The three things are considered in stand point of uncertainties are listed as, (i) Future load growth, (ii) Variation in the solar radiation, (iii) Wind output variation. The challenge in Optimal DG Placement (ODGP) needs to be solved with optimization problem with many objectives and constraints. The ODGP is going to be done here, by using Non-dominated Sorting Genetic Algorithm II (NSGA II). NSGA II is one among the available multi objective optimization algorithms with reduced computational complexity ($O=MN^2$). Because of this prominent feature of NSGA II, it is widely applicable in all the multi objective optimization problems irrespective of disciplines. Hence it is selected to be employed here in order to obtain the reduced cost associated with the DG units. The proposed NSGA II is going to be applied on the IEEE 33-bus and the different performance characteristics were compared for both wind and solar type DG units.

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I. INTRODUCTION

Fossil fuel based energy has certain limitations such as availability of transmission corridors and the gradual increase in the global temperature, rapid development of Distributed Generators (DGs) has been observed around the world. DGs are categorized into renewable and fossil fuel-based sources. Renewable energy sources comprise of wind turbines, photovoltaic, biomass, geothermal, small hydro and so on. Fueled DGs are internal combustion engines, combustion turbines and fuel cells. The employment of DGs is helpful for the following (i).Reducing primary energy consumption, (ii). Decrease the emission of greenhouse gases and, hence, alleviating global warming, (iii). Reducing transmission losses.

Penetration of DGs could lead to some risks to secure and economic operation of power systems. The main drivers behind the focus on DG integration, especially of the renewable type, in many countries around the world are discussed in [1]. Due to the increasing penetration level of DGs in distribution systems, the siting and sizing of DGs in distribution system planning has become increasingly important. The aim of the optimal DG placement (ODGP) is to provide the best locations and sizes of DGs to optimize electrical distribution network operation and planning taking into account DG capacity constraints. Several models and methods have been suggested for the solution of ODGP problem. In [2], presents an overview of the state of the art models and methods applied to the ODGP problem. In [3], numerous strategies and methods that have been developed in recent years for DG integration. Planning and a critical review of the work is discussed along with the barriers to implement the advanced techniques are out-lined.

Uncertainties considered includes, (i) wind speed variation, (ii) output power of photovoltaic (iii) future load growth. Modelling of these uncertainties like future load growth and photovoltaic are proposed in [4] and [5]; modelling of wind and electricity prices are explained in [6]; the uncertainty in fuel price model is proposed in [4] and [7].

In this proposed paper the candidate bus selection is done based on the index End Node Voltage Violation Index [8] and the algorithm used in this paper is GA.

Now a days, optimal siting and sizing of DGs is the wide area and many research papers are proposed [9]–[14] and those are based on various methods such as deterministic and heuristic methods. In [4], a Probabilistic Power Flow (PPF)-embedded Genetic Algorithm (GA)-based approach is proposed in order to solve the optimization problem that is modelled mathematically under a Chance Constrained Programming (CCP) framework. Point Estimate Method (PEM) is proposed for the solution of the involved PPF problem. GA is applied in order to find the optimal plan. If GA is employed in this paper which has high computational complexity and not suits for multiobjective optimization problems. In [5], under the CCP framework, a new method is presented to handle uncertainties in the optimal siting and sizing of DG. Monte Carlo simulation (MCS) embedded genetic algorithm based approach is employed to solve the developed CCP model. In [9] optimal location of a DG, in radial as well as networked systems with the minimization of the network loss as the objective. Both the above discussed papers employed with the analytic methods and that are easy to implement and fast to execute. However, their results are only indicative, whereas heuristic methods gives better result than analytic method. In [6], a deterministic planning problem methodology based on generating probabilistic generation-load model that combines all possible operating conditions of the renewable DG units with their probabilities has been proposed for optimally allocating different types of renewable DG units in the distribution system so as to minimize annual energy loss. The random behaviors of solar irradiance and wind speed are modeled by means of Beta and Rayliegh distributions, respectively. If the probabilistic load model is employed may lead to violation in certain limits and cause this approach as less accurate. In [10], a new optimization algorithm based on integrating the use of genetic algorithms and tabu search (GA – TS) methods is used for optimal allocation of dispersed generation in distribution networks. In the above paper cost based analysis is not included in the analysis. For cost based multiobjective analysis with proposed GA - TS algorithm fails to give accurate results. Artificial Bee Colony (ABC), a new metaheuristic, population-based optimization technique is proposed in [11] to determine the optimal DG-unit's size, power factor, and location in order to minimize the total system real power loss. The ABC algorithm is simple, easy to implement, and capable of handling complex optimization problems but less convergence in large systems. In [12], Improved Multi-Objective Harmony Search (IMOHS) a multiple objective planning framework is proposed to evaluate optimal location and size of DGs. The results of IMOHS are compared with NSGA II, but in the multiple objective function optimal location and sizing only included whereas the type of that DG is not considered. In [13], a multi-objective index-based approach for optimally determining the size and location of multi-DG units in distribution systems with different load models is proposed. This analysis, includes load models for size–location planning of DGs in distribution system. If in the case of probabilistic and time varying loads the computational complexity of the PSO may increase. GA and decision theory are applied to optimize sizing of DG under uncertainty including power quality issues is discussed in [14]. Modelling of uncertainties in wind speed and

photovoltaic irradiation are as not accurate as proposed in [4] and [5]. Heuristic methods [11] – [14] are usually robust and provide near optimal solutions for large, complex ODGP problems but, they require high computational efforts. The methods applied to the optimization problem in distribution networks together reviewed in [3].

The solution of the power flow problem helps evaluate the state of the power system for a specific set of values of the input variable. In case of uncertainties in the input variables of the power system, it is desirable to assess the system output variables (bus voltages and line flows) for many load and generation conditions. It is necessary to run many times the deterministic power flow routine in order to evaluate possible system states. In [15], algorithm for the calculation of power flow in a distribution network with dispersed generation is presented and implemented in MATLAB code and different types of representative distribution generation profiles and load profiles were adopted.

Recently, a large number of multi objective evolutionary algorithms (MOEAs) are available in [16], a systematic comparison of various evolutionary approaches to multiobjective optimization using six carefully chosen test functions and suggest that such an algorithm may be constructed, where probably the nondominated sorting classification as well as elitism play a major role. A fast and elistic algorithm called nondominated sorting genetic algorithm version II (NSGA-II) is introduced by K.Deb in [17]. It is the next version of NSGA and has the advantages like reduced computational complexity, better awareness in lack of elitism and elimination of sharing parameters over earlier version. The NSGA-II algorithm has been compared with another recently suggested constraint-handling strategy. These results encourage the application of NSGA-II to more complex and real-world multiobjective optimization problems. In [18], an improved NSGA II algorithm is employed for optimal DG placement considering line losses, voltage stability and voltage deviation as multi objectives.

In this paper contains, modelling of uncertainties like wind speed variation, solar illumination and of the uncertainties in the future load growth in distribution system is given in Section 2. The Power flow calculation for the distribution network is outlined in Section 3. In Section 4, the problem formulation under uncertainties by using the mathematical modelling is explained. The proposed ENVVI based approach for optimal location is described in Section 5. In Section 6, the proposed NSGA II based method is applied for solving the ODGP problem of the IEEE 33-bus distribution network and the obtained results verify the effectiveness and the validity of the proposed method. Results and discussion are explained in Section 7. Conclusions are given in Section 8.

II. Modeling of Uncertainties

A. Load Modelling

Using statically studies and the historical data, it has been found that the load growth of bus i at year t, ΔP_L (t) follows the normal distribution with mean μ and standard deviation σ.

The Probability Density Function (PDF) is given below,

$$\Delta P_L = \left\{ \frac{1}{n-1} \sum_{i=1}^{n} (x_i - \bar{x})^2 \right\}^{\frac{1}{2}}$$

B. Solar Modelling

On using the historical and meteorological data for each region, it has been observed that the solar illumination intensity approximately follows the Weibull distribution, hence the PDF is given below,

$$f(v) = \frac{k}{c^k} v^{k-1} \exp\left(\left(\frac{v}{c}\right)^k\right), \quad 0 < v < \infty$$

Where,

v – wind speed in m/sec

k , c^k – shape and scale index respectively, of the Weibull distribution

C. Wind Modelling

Many experiments have demonstrated that a good expression for modelling the stochastic behavior of wind speed is the Weibull probability density function (PDF). The PDF is given below,

$$f(s) = \frac{k_s}{c_s^{k_s}} s^{k_s-1} \exp\left(\left(\frac{s}{c_s}\right)^k\right), \quad 0 < s < \infty$$

Where,

s – Solar illumination intensity

k_s , c_s – shape and scale index respectively, of the Weibull distribution of s

III. Power Flow Algorithm

The load flow of a power network provides the steady state solution through which various parameters of interest like currents, voltages, losses etc., can be calculated. The load flow is important for the analysis of distribution system, to investigate the issues related to planning, design and the operation and control. Some applications like optimal DG placement and distribution system and distribution automation system, requires repeated load flow solution.

In this contemporary investigation, forward-backward sweep algorithm is adopted to observe the load flow solution for balanced radial distribution system. This method avoids the repetitive computations at each branch and makes this approach as computationally effortless and competent.

A novel approach for the load flow analysis of a radial distribution system which is simple to implement and

efficient in computation has been proposed and described in detail. The computational efficiency and speed of the proposed method has been tested in 33 bus radial distribution network. It can be concluded that the simplification made in the branch current computation of the proposed approach has resulted in improved computational speed of load flow analysis of radial distribution system.

Backward sweep updates currents using Kirchhoff's Current Law (KCL).

$$I_S = D\, I_R$$

In forward sweep updating the voltage

$$V_S = A\, V_R + B\, I_R$$

IV. End Node Voltage Violation Index

The voltage level at the end nodes of a distribution system is always comparatively dropping in nature than the other nodes in the system [8]. So as to maintain this dropping voltage level as original, a solution is prescribed in this research effort by finding the proper placement of DG units. In order to discover the apt location for placing DG units, a new index called End Node Voltage Violation Index (ENVVI) is proposed in this paper [8].

In order to confine the search space to only some buses, tail end nodes are identified directly from the network structure of distribution network. The ENVVI is calculated using Eq.1. by piercing DG with 50% of the total feeder demand at each node. When DG is connected at bus i, FNVDF for bus i, is given below in equ.1

$$\mathrm{ENVVI}_i = \sum_{m=1}^{NTEN} \frac{(V_{nominal} - V_m)^2}{NTEN}$$

where,

V_m is the voltage of bus i

N_{TEN} is the number of tail end nodes

$V_{nominal}$ is the nominal value of voltage and is taken as 1 p.u.

V. Non Dominated Sorting Genetic Algorithm II

The GA is an evolutionary artificial intelligence technique that has been used as an optimization tool in different areas, including engineering, science, and commerce. It consists of the following steps: codification of individuals (chromosomes), population generation, evaluation (fitness), crossover mutation and selection. There has been much work published on the application of GAs to the DSR problem. In the objective functions and constraints are converted into a single objective by using weighting factors. Also, in fuzzy-GA approaches the multi-objective problem is formulated by representing each objective function using a suitable fuzzy membership function. Although the importance of the objective functions is problem independent, their values and the problem constraints are problem dependent. Thus, these methods suffer from the need to choose suitable weighting factors and parameters of the fuzzy sets for each system. To overcome the above drawbacks, a non-dominated sorting GA II (NSGA-II) was introduced in general form to be applicable to any multi-objective problem. Flow chart of the NSGA II along with the proposed work is shown below in fig.1.

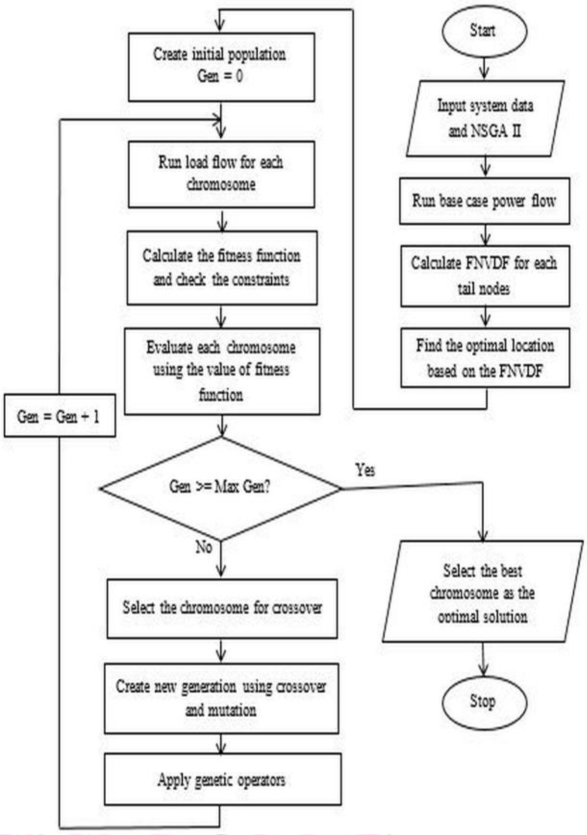

Fig.1 Flow chart of the propose work

VI. Results and Discussions

To examine the effectiveness of this technique, the simulation tests are performed in IEEE 33 bus radial distribution test systems and its single line diagrams which are depicted in Figure 2 below. The fundamental data of these test systems are taken from references [4]. The necessary codes are developed in Matlab release 2012 with Intel core I3 processor and 4 GB RAM.

The data for the uncertainty of load, solar and wind parameters are taken from reference [4] and cost of individual DG units such investment, operating and maintenance cost also taken from reference [4].

The potential places for the DG location is shown below

in table 1, column 2 represents the minimum values of ENVVI and the corresponding location were chosen to be as optimal locations.

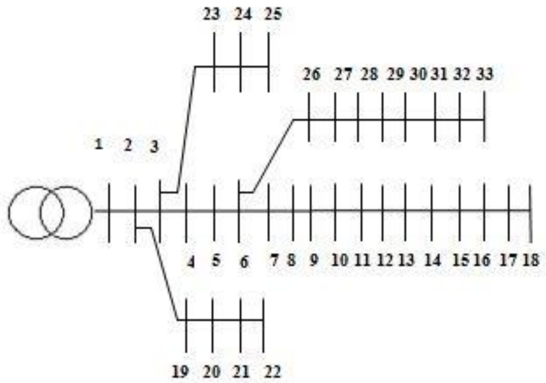

Figure: 2 IEEE 33 bus radial distribution system

Table: 1 Optimal Location based on ENVVI

S.No	ENVVI	Optimal Locations
1	0.0003432	9
2	0.0003567	10
3	0.0003813	11

DGs are inserted at these selected best locations in such a way that the size of the DG is varied from minimum value to maximum value. For both the test systems, the size of the DGs is varied from 300 KW to 600 KW. The sizes which provide the minimum real power losses are the best size of DGs to be placed at these optimal locations.

The comparison results are given below in table.2. below, as given table in column 1 type of DG units are denoted, in column 2 the capacity of each DG units are tabled and the corresponding loss and total cost are given in column 3 and 4 respectively. The percentage of loss reduction is shown in column 3 within brackets. Table.2. is taken for considering the top two locations similarly for 3 locations the results are compared in table.3.

Table: 2 Comparison of Results for 2 DG units

Type	Bus No	DG Size (KW)	Loss (KW)	Total Cost ($)
Wind	9 10	600 583.56	129.54 (41.87%)	236674
Solar	9 10	595.32 600	129.18 (42.03 %)	215160

From table 2 and 3 it is clear that the loss reduction is moreover same for both the DG types but in the case of total cost solar DG gives better result in both the cases. Similarly the fitness curve for the two DG types are shown below in fig.3. and fig.4. From the graphs it is observed that the optimal point is showing that 123 KW for loss and total cost is around 10000 $.

Table: 3 Comparison of Results for 3 DG units

Type	Bus No	DG Size (KW)	Loss (KW)	Total Cost ($)
Wind	9 10 11	584.54 446.37 532.76	123.58 (44.54 %)	312736
Solar	9 10	595.32 600	129.18 (42.03 %)	215160

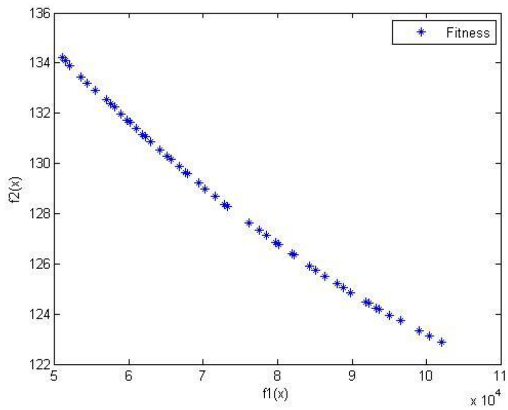

Figure: 3 Fitness Curve for Solar

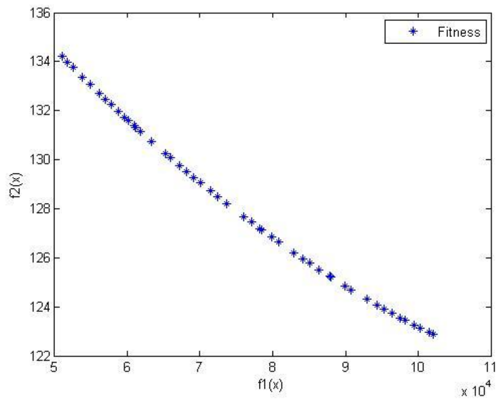

Figure: 4 Fitness Curve for Wind

Similarly the improved voltage profile after the DG units installation is shown below in fig.5. and fig.6. for Solar and Wind type of DG, respectively. From that graph it is concluded that the voltage has been improved in the optimally selected locations irrespective of DG types.

VII. Conclusion

The problem framed in this attempt is formulated as an optimization problem using NSGA II with an objective of minimizing total cost and real power losses and bus voltage deviations subject to diverse numbers of equality and inequality constraints. It is evidently confirmed that the interconnection benefits of DG are getting enhanced with the increased penetration of DG units. A significant improvement in voltage profile as a supplementary gain by the optimal DG units' placement has also been observed and demonstrated in this investigation.

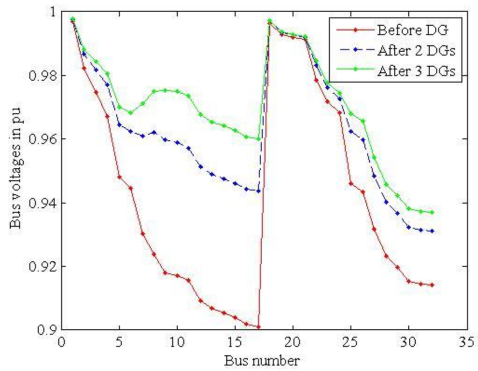

Figure: 5 Improved voltage profile for Solar

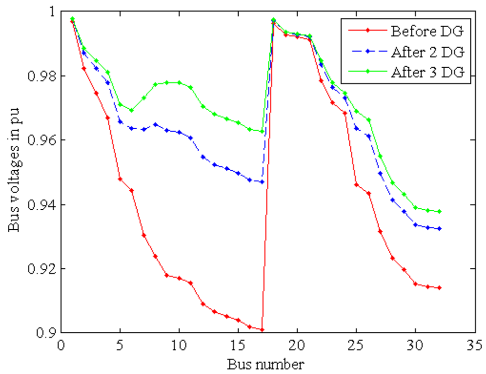

Figure: 6 Improved voltage profile for Wind

The results derived from this methodology are compared for the same problem for the two different DG types such as solar and wind. From the graphs and tables it is concluded that solar is better compare to the wind unit. Though solar has certain limitations can be placed in the optimal locations with the minimum cost.

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